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SOME SUPERHIGH-FREQUENCY AND MAGNETIC PROPERTIES OF CHEMICALLY PRECIPITATED FILMS

by

L.V. Kirenskiy [DECEASED], N.S. Chistyakov, et al.

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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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SOME SUPERHIGH-FREQUENCY AND MAGNETIC PROPERTIES OF CHEMICALLY PRECIPITATED FILMS

L. V. Kirenskiy [DECEASED], N. S. Chistyakov, L. A. Chekanova, B. P. Tushkov, G. I. Fish.

Magnetic films obtained by the method of chemical deposition have in recent years attracted the attention of researchers because of a number of their interesting properties, comparatively simple technology of deposition and some possibilities of practical utilization.

For the purpose of obtaining additional information about the physical properties of chemically precipitated films and searching for the possibilities of their practical utilization in superhigh-frequency technology we investigated Co-p magnetic films in the range of the superhigh frequencies (f=9000 MHz).

The fundamental superhigh-frequency parameters of films (width and intensity of the line of ferromagnetic resonance, the components of complex shf susceptibility, etc.) were investigated on a standard shf spectrometer with the recording of differential curves of resonance absorption. Measurement of components of complex shf susceptibility was conducted on a setup described in detail earlier (3, 4). On the same in accordance with (5) were studied the processes of quasi-static magnetic reversal. The structural properties of films were investigated by the method of X-ray diffraction analysis. Chemical analysis was conducted by the calorimetric method.

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The films being investigated, with a thickness of the order of one micron, were deposited on copper and lavsan (polyethylene terephthalate film, Soviet equivalent of Dacron) substrates processed with standard technology (1). The substrate was a solution (2) containing 0.07 mole/l $CoSO_4$, 0.2 mole/l of sodium hypophosphite, 0.2 mole/l of sodium citrate, 0.6 mole/l of ammonium sulfate, and the pH solution was brought to 9 using NaOH. Subsequently the concentration of one of the components alternately was changed over a wide range values.

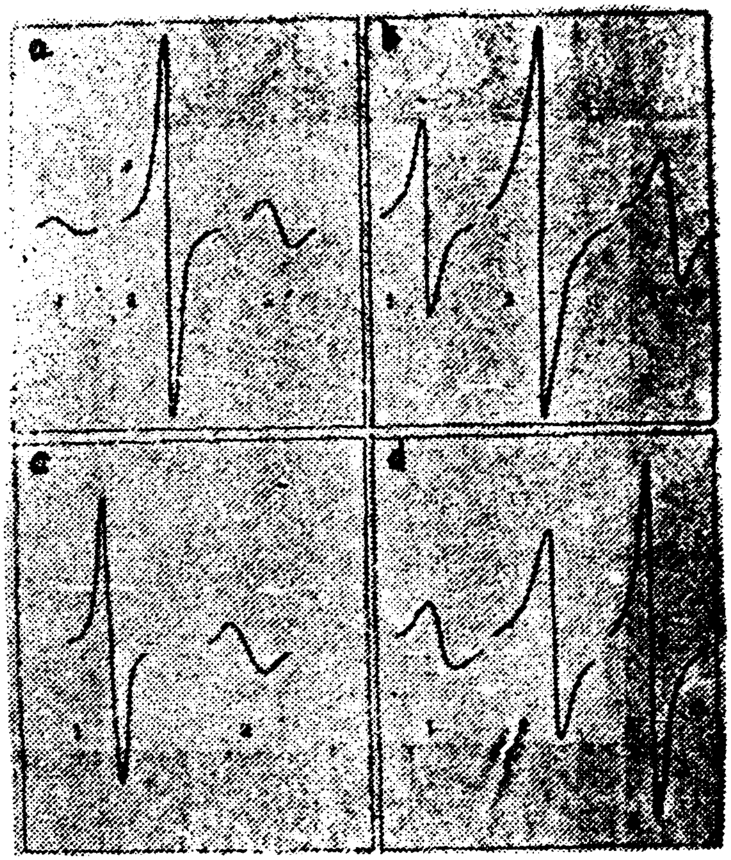

Fig. 1. Curves of ferromagnetic resonance absorption of films Co-P obtained with different contents in bath of sodium hypophosphite (5, 15, 70 g/l) "a", sodium citrate (100, 250, 400 g/l) - "b", ammonium sulfate (10, 250 g/l) - "c", and different pH (9; 8; 7; 3) - "d". ΔH curves 1, 2, 3 Fig. "a" are equal to respectively 360, 140, 400 Oe; ΔH curves 1, 2, 3 Fig. "b" - 190, 140, 300 Oe; ΔH curves 1, 2 Fig. "c" - 140, 400 Oe; ΔH curves 1, 2, 3 Fig. "d" - 360, 140, 140 Oe.

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The films, obtained from the initial solution possessed wide lines of absorption ($\Delta H \approx 1000$ Oe). For the determination of the possibility of obtaining films with the best resonance parameters the deposition of films was conducted under varied conditions. The content of salt of cobalt, sodium hypophosphite, sodium citrate, and sulfate ammonium was changed for this in the solution, and the acidity of the solution also was changed.

With a change of sodium hypophosphite concentration within the limits of 5-70 g/l (Fig. 1a) the line of ferromagnetic resonance undergoes significant change. A noticeable effect on shf parameters of films is demonstrated by the concentration of sodium citrate in the solution (Fig. 1b). The films obtained from a solution containing 50 g/l of sodium citrate, possessed a wide line of resonance absorption ($\Delta H \approx 1000$ Oe) and weak intensity. In the figure this curve is not given. An increase in the concentration of sodium citrate to 250 g/l leads to the decrease of the width of line. However, further increase in the content of sodium citrate in the solution again leads to an increase in the width of the curve and a decrease of the intensity of the line. Ammonium sulfate exerts a substantial influence on the parameters of the curve of resonance absorption only at significant concentrations (Fig. 1c). A change in the content of cobalt salt in the solution in the significant limits (1-150 g/l) does not have a noticeable effect on the resonance properties of films. The resonance characteristics of films are significantly affected by the acidity of solution. Figure 1d gives the curves of the resonance absorption of films obtained with different solution pH values.

The comparison of the results of the investigation of the resonance properties of films with the results of chemical and X-ray diffraction analyses makes it possible to draw some conclusions. Observed in films which possess the most intense and narrow lines of absorption, as a rule, is observed the increased content of phosphorus, and in this case the X-ray diffraction analysis shows the absence of clearly expressed crystal structure. Thus, for the films whose resonance curves are represented in figure 1b, it was established that change of the content of sodium citrate in the solution from 50 to 250 g/l leads to a change in the content of phosphorus in the deposits from 3 to 20%.

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The films which contain 3% of phosphorus give in the X-ray photograph of sharp diffraction lines of reflection. The deposits possess a hexagonal structure typical of cobalt. The size of crystallites is approximately 500 Å. For films obtained from the solution containing 250 g/l of sodium citrate X-ray lines of reflection were not observed. The latter suggests that these deposits either are "amorphous" or have a strongly distorted crystal structure (6, 7, 8).

For obtaining additional information about the connection of the resonance properties of films with their crystal structure we carried out experiments on the effect of the annealing of films on the resonance parameters. Annealing was conducted in vacuum at 10^{-5} m Hg and 300°C. Films with narrow and wide lines of resonance absorption were selected for annealing. It was established that the annealing of films which have a narrow line of absorption leads to its widening (Fig. 2). In films which possess a wide resonance curve, after annealing the width of line virtually is not changed. X-ray diffraction analysis showed that after the annealing of "amorphous" films (i.e. with a narrow line of resonance absorption) there appeared a clearly expressed crystal structure with grain size of approximately 1000 Å.

Thus, the results of investigation of the resonance properties of chemically deposited Co-P films make it possible to assert that for films which possess wide lines of resonance absorption a low content of phosphorus and the presence of a crystal structure, in particular hexagonal are characteristic. In view of the high anisotropic constant, the resonance conditions for uniaxial crystallites, arbitrarily oriented in film can differ considerably. As a result of this the resonance curves of such films, which are the superposition of resonance curves of individual crystallites, can be widened considerably. Films with low line width values are characterized by a significant content of phosphorus and by the absence of a clearly expressed crystal structure. All these data will agree with the results of research on ferromagnetic resonance in "amorphous" Co-Au films (9). Similar results were obtained by us for Co-P films deposited on dielectric substrates (Lavsan) and for films created by the electrolytic method.

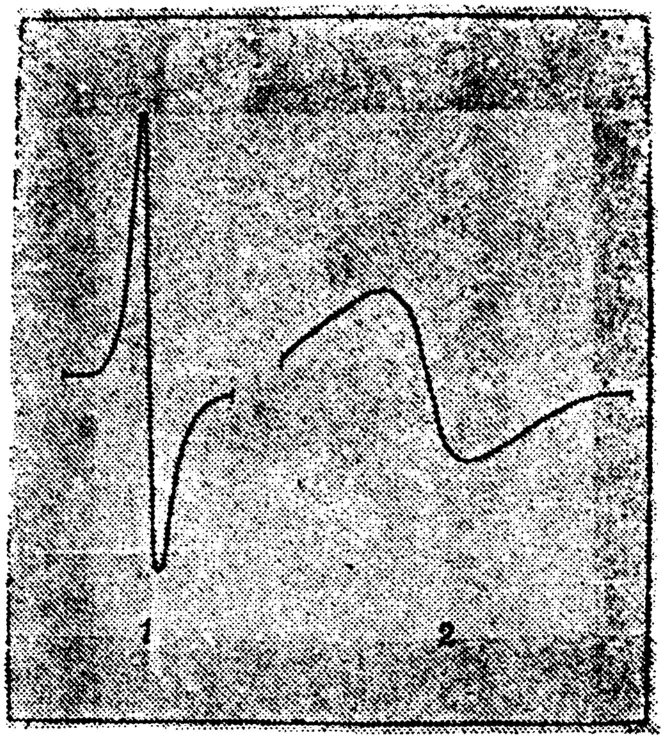

Fig. 2. Curves of ferromagnetic resonance absorption of Co-P films before annealing (curve 1) and after annealing (curve 2) "1" - ΔH = 140 Oe; "2" - ΔH = 720 Oe.

Together with the study of resonance properties were investigated the superhigh-frequency properties of films in weak magnetic fields far from ferromagnetic resonance, and also measured were the components of complex shf - susceptibility. Such investigations are of interest for evaluating the possibilities of practical utilization of magnetic films in shf devices controlled by means of an external magnetic field. Fig. 3 depicts the curves of variation in the components of complex shf susceptibility of films in weak magnetic fields under the conditions of their quasi-static magnetic reversal (Fig. 3a) and in fields corresponding to ferromagnetic resonance (Fig. 3b). The films for which are given curves 1, 2, 3 were discussed by us above (see Fig. 1b). The curves were recorded on chart paper with a two-coordinate recording instrument.

χ and χ, in relative units

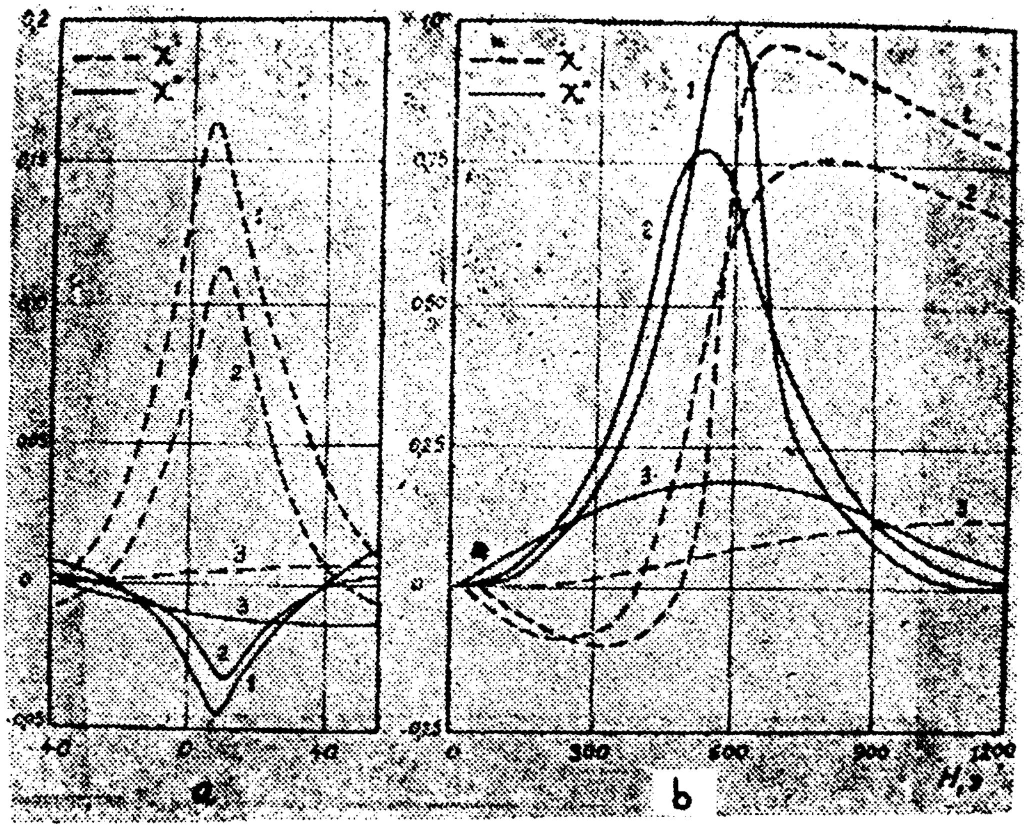

Fig. 3. Curves of change in complex shf susceptibility of films in weak magnetic fields under conditions of their quasi-static magnetic reversal - "a" and in fields corresponding to ferromagnetic resonance - "b".

The path of these curves in weak magnetic fields can be explained on the basis of relationships established by us earlier in the investigation of shf susceptibility of uniaxial magnetic films obtained by thermal atomization in vacuum. Actually, in (4, 5) it was shown that a change in shf susceptibility depends on the nature of the process of quasi-static magnetic reversal of films, and it occurs only when with magnetic reversal the processes of rotation of the magnetization vector occur (independently one-way or two-way). But if magnetic reversal is realized by a shift of 180° domain boundaries, then a change in shf susceptibility in the process of magnetic reversal of the film is not observed.

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In this case the maximum changes in shf susceptibility occur in the fields corresponding to the maximum change of the projection of magnetization intensity in the direction of the superhigh-frequency field. For the uniaxial films with their magnetic reversal in the direction of the hard axis the maximum value of susceptibility is observed in the fields which correspond to the values of coercive force. For chemically deposited Co-P films these patterns also occur. In this case it is revealed that with the decrease of the content of phosphorus the coercive force of films grows (Fig. 3a).

From the analysis of data on the change in the components of complex shf susceptibility with the magnetic reversal of chemically deposited films along different directions it was established that in the majority of the cases they were isotropic. The insignificant anisotropy discovered for some films apparently is caused by the texture of the substrate.

In accordance with the procedure, described in detail in (5), by observing the signal of a change in shf susceptibility of films with magnetic reversal in rotating and linearly polarized fields it is possible to estimate the contribution of rotation of the magnetization vector to the general process of magnetic reversal. Investigations showed that in chemically deposited films a large part of their volume (60-80%) is remagnetized by the process of rotating the intensity of magnetization. Despite the fact that the domain structure could not be observed due to poor surface condition, it can be assumed that the processes of shifting the interdomain boundaries with magnetic reversal in chemically deposited films also occur.

From the results of the conducted investigation it is possible to draw the conclusion that by the method of chemical deposition it is possible to obtain films whose superhigh-frequency parameters in a number of cases are comparable with the corresponding parameters of films obtained by the method of thermal deposition in vacuum. On the other hand, it is comparatively simple to obtain samples whose superhigh-frequency parameters are changed in a wide interval of values. However, as far as the superhigh-frequency properties of electrolytic films are concerned, they, as investigations showed, do not at all differ from the properties of films obtained by the method of chemical deposition.

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At the same time the latter method has an important advantage over the electrolytic, since it makes it possible to deposit films to on dielectric substrates. This, in particular, offers great possibilities not only for expanding the range of the investigations of these films in the range of superhigh frequencies, but it also can prove to be decisive in their practical utilization.

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